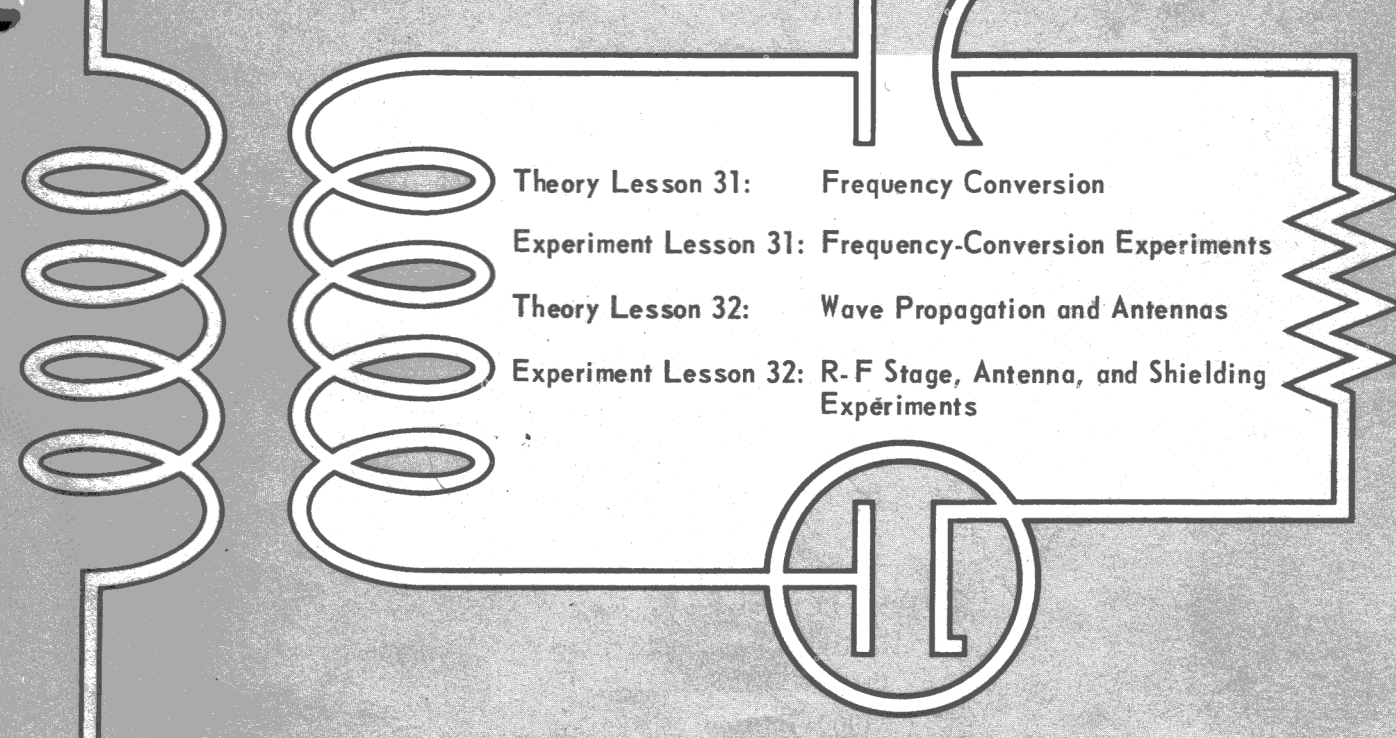


ELECTRONIC FUNDAMENTALS



The graphic consists of a vertical line on the left that transitions into a series of horizontal loops, resembling a spring. To the right of this is a large, stylized letter 'E' that is partially enclosed by a circular shape. The text is positioned within the central horizontal bar of the 'E'.

Theory Lesson 31: Frequency Conversion
Experiment Lesson 31: Frequency-Conversion Experiments
Theory Lesson 32: Wave Propagation and Antennas
Experiment Lesson 32: R-F Stage, Antenna, and Shielding Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 31

FREQUENCY CONVERSIONS

- 31-1 How the I-F Frequency is Produced
- 31-2. How the I.F. is Recovered
- 31-3. The Pentagrid Converter
- 31-4. Improved Converter Tubes
- 31-5. Diode Tubes and Crystal Rectifiers as Mixers
- 31-6. Conversion Transconductance
- 31-7. Converter Troubles



RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Theory Lesson 31

INTRODUCTION

The operation of the mixer or converter stage is complex and fascinating. It combines the incoming modulated r-f signal and a locally generated signal, both of which are applied to its input. At the output of the converter is a signal *equal to the difference between the frequency of the incoming signal and the frequency of the oscillator signal*. This output, called the difference frequency, has the modulation of the incoming r-f signal. The difference-frequency signal may be considered as the r-f carrier converted to a lower frequency. It is a carrier, and *its* envelope contains the original audio modulation. The frequency of this carrier is lower than any frequency in the broadcast band, but higher than any audio frequency. It is an intermediate-frequency carrier.

The principal parts of the mixer stage are:

- a. A mixer tube.
- b. An oscillator tube.
- c. An r-f input circuit tuned to the desired carrier.
- d. An oscillator resonant circuit tuned to a frequency higher than the r.f. by an amount equal to the desired intermediate frequency.

Without the mixer or converter stage, the superheterodyne receiver would not exist.

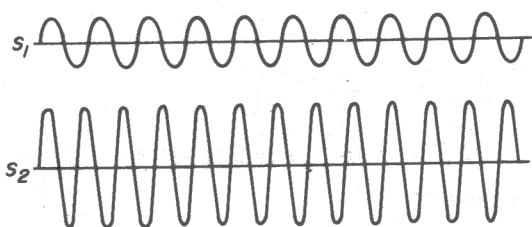


Fig. 31-1

The change in frequency that results when the carrier passes through the mixer makes possible the tremendous advantages that the superheterodyne has over all other types of radio receivers.

31-1. HOW THE I-F FREQUENCY IS PRODUCED

Shown in Fig. 31-1 are two a-c signals that will be applied to a mixer. When two signal currents of different frequencies flow in the same circuit, their alternations may at one instant flow in the same direction. But because their frequencies differ, they will not remain in step. After a short interval, the alternations of one will be in the opposite direction to the alternations of the other. After another such interval, the alternations will again be in step. After another such interval, they will again be out of step, and so on.

When they are flowing in the same direction, they reinforce each other — that is, they add, making the total current flowing in the circuit at that instant greater than either signal alone.

When they are later flowing in opposing directions, they cancel. If they are of equal amplitude, they cancel completely. If one is greater than the other, the smaller current cancels an amount of the larger current just equal to the smaller signal. In effect, the smaller current is subtracted from the larger. The amount remaining is the total current flowing in the circuit at that instant.

When the two are neither exactly in step nor exactly opposing, but somewhere in between, they partially add or partially cancel according to their relative directions of flow.

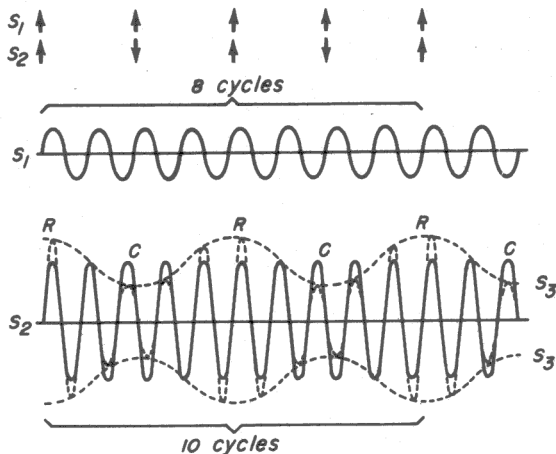


Fig. 31-2

The result, shown in Fig. 31-2, is that the smaller of the two signals, (S_1) is first added to the larger, (S_2) then subtracted from it, then added, then subtracted, and so on.

At the points in the drawing marked *R*, for reinforce, the currents are in phase. The dashed line shows the smaller current added to the larger. At the points marked *C*, for cancel, the currents are out of phase. The dashed line shows the reduced amplitude of the larger current after the smaller current has been subtracted from it. Note that the over-all effect upon S_2 of the periodic additions and subtractions is that the amplitude of S_2 varies regularly, as shown by the dashed line.

Note also that the upper and lower halves of the envelope of S_2 are symmetrical with respect to the axis. If either half of the envelope could be conveniently separated from S_2 , its outline would be a sine wave having a frequency lower than that of S_2 .

The figure shows that during the time that S_2 goes through 10 cycles, S_1 goes

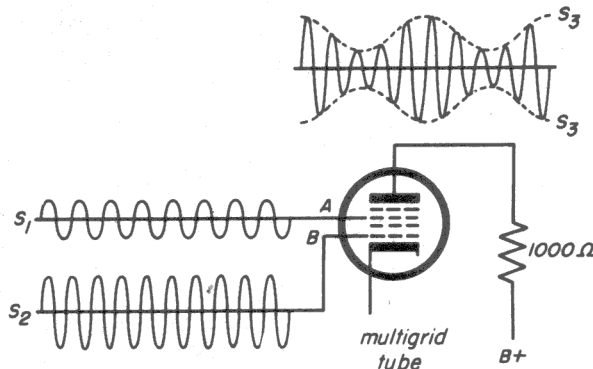


Fig. 31-3

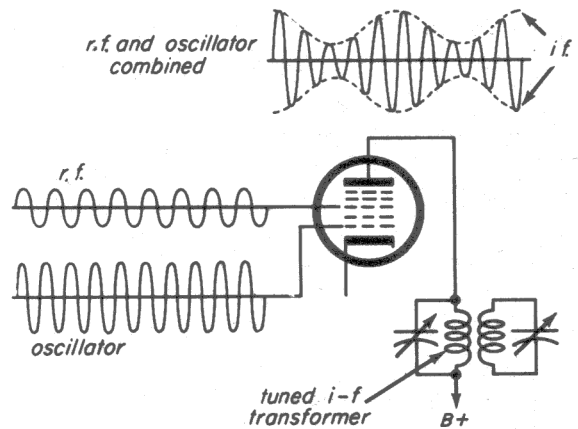


Fig. 31-4

through 8 cycles. In the same time, the outline of the envelope goes through 2 cycles. The frequency of the outline is equal to the difference between the frequency of S_2 and that of S_1 . If S_2 were 1,455 kc and S_1 were 1,000 kc, the frequency of the outline would be their difference, 455 kc.

Now suppose we apply an oscillator signal, S_2 , at 1,455 kc, and an r-f signal, S_1 , at 1,000 kc, to the inputs of a multigrid tube, having a resistor for its plate load, as shown in Fig. 31-3. The two input signal currents, flowing through whatever impedances are in the grid circuits, will cause varying voltage drops across the impedances. These varying voltage drops will have the same waveforms as the currents producing them. Each voltage waveform on the grid will cause the tube's plate current to vary correspondingly. S_2 and S_1 will appear in the plate circuit as current variations through the resistor. In the plate circuit, the two currents will add and subtract, just as depicted in Fig. 31-2. S_1 will be superimposed on S_2 . If the tube has a linear grid-voltage - plate-current transfer curve, S_3 will have a symmetrical envelope whose outline varies at 455 kc. The rate at which amplitude varies is the frequency difference between the two input signals.

31-2. HOW THE I.F IS RECOVERED

Although the 455-kc signal is the one we desire to recover from the plate circuit, we cannot separate it simply by substituting for the resistor a transformer tuned to 455 kc, as shown in Fig. 31-4. In its present form,

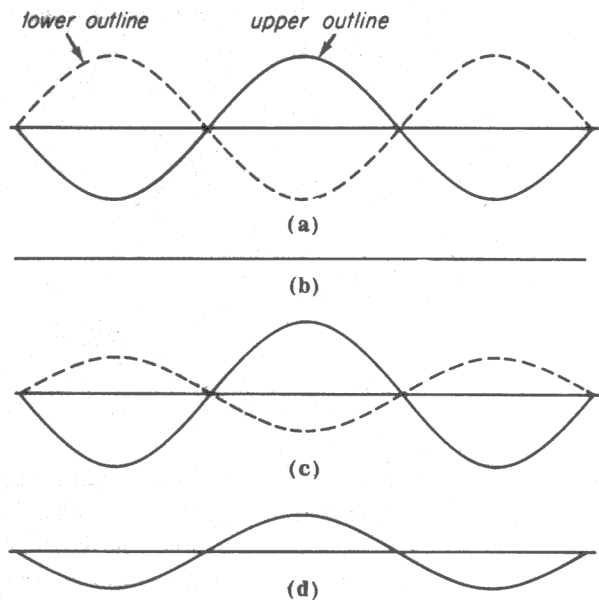


Fig. 31-5

two symmetrical half envelopes, the 455-kc modulation cannot be separated from the other signals by a tuned circuit because the waveform of the upper and lower halves of the envelope are exactly equal and opposite in phase. This is more clearly shown in Fig. 31-5, where the outlines alone are considered, in order to illustrate the principle involved in separating the 455-kc component.

At *a*, the two outlines are shown on a common axis to emphasize their equal and opposite character. At *b*, their resultant — zero — is shown. No recoverable waveform remains. But if the two outlines are of unequal amplitude, as at *c*, the smaller in amplitude would be unable to completely cancel the larger. A resultant would remain, as at *d*. This resultant could be recovered by a transformer tuned to its frequency. It could be passed on to the following stage for amplification.

The process that makes the amplitude of the outlines unequal is called heterodyning. It takes place in the mixer tube. It is due to the nonlinear e_c-i_b characteristic of the tube, or to operation beyond cutoff, or to simple rectification, depending upon the type of mixer used. It causes one outline to be amplified more than the other, or one outline to be eliminated. In each case, a resultant remains.

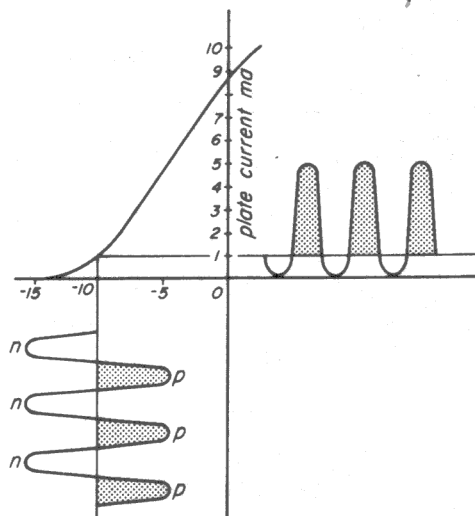


Fig. 31-6

The effect of a nonlinear curve upon a signal is illustrated graphically in Fig. 31-6. The negative swings of the signal (marked *n*) on the grid produce much less change in plate current than positive swings (marked *p*) of the same amplitude. Therefore, the reproduced signal is greatly distorted, but in a useful way. The part of the envelope under the axis is relatively compressed, whereas the part above the axis is relatively much enlarged.

If the oscillator signal is heterodyned with a modulated r-f signal, the output of the mixer tube at the i.f. is also modulated. But the upper and lower outlines of the modulation envelope will not be equal in the reproduction, as shown by Fig. 31-7. As in the

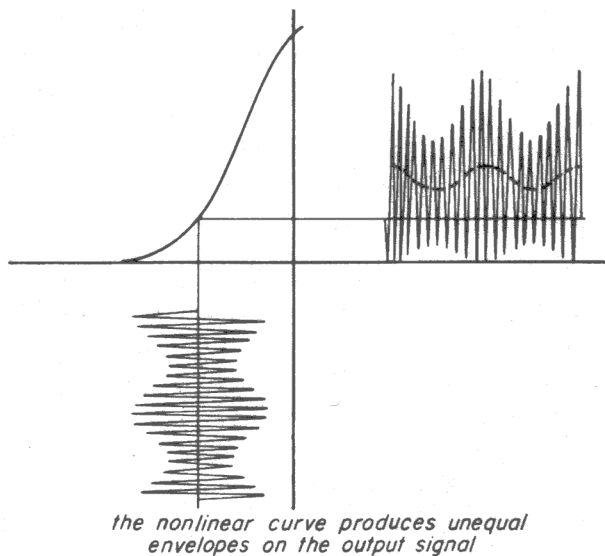


Fig. 31-7

preceding figure, the lower half will be compressed, relative to the upper half. The modulation in the lower half will also be compressed relative to the modulation in the upper half. A resultant (shown in the figure as a dashed line) will be produced. This is the condition necessary for recovery of the modulation wave. An i-f transformer in the plate circuit of the tube, tuned to the resultant, will separate the i.f. from the other signals.

Nonlinear Impedance. When two signals of frequencies f_1 and f_2 are applied to an input of a nonlinear circuit, the output will contain many signals. The output will contain a combination of signals the frequencies of which are f_1 and f_2 . The output will also contain another signal the frequency of which is equal to the sum of f_1 and f_2 ; another signal of frequency equal to the difference of f_1 and f_2 ; and still other signals called harmonics. In effect, when f_1 and f_2 are applied to a nonlinear circuit, the output is distorted. Ordinarily, distortion, such as in an a-f amplifier, is not desirable. But, in certain circuits, such as mixer and converter circuits, distortion is useful. At the output of a mixer or converter, any specific signal (f_1 , f_2 , $f_1 + f_2$, $f_1 - f_2$, etc.) can be selected and the others rejected by use of a tuned circuit.

Let us discuss what is meant by the term nonlinear circuit or nonlinear impedance. You may occasionally read about mixers or converters and find that they are referred to as nonlinear impedances. First, let us note that the electron stream in an electron tube may be considered to be a variable resistor. The resistance of the electron stream is varied by changing the grid voltage while the plate voltage is kept constant. When the grid is made less negative, more plate current flows via the electron stream. If the density of the electron stream becomes greater — that is, a greater current flows, even though the plate voltage is unchanged — the electron stream is equivalent to a resistor of lower value. When the grid is made more negative, less plate current flows via the stream. Thus, the electron stream is equivalent to a resistor of higher value be-

cause it conducts less current for a given applied plate voltage.

However, the change in the resistance need not be linear. If we refer to the e_c-i_b curve for a frequency-converter or mixer tube, in Fig. 31-6, we can see that when the voltage on the control grid changes from -10 volts to -3.5 volts, a change of 6.5 volts, the plate current increases by 4 ma. But when we change the control-grid voltage in the other direction, from -10 volts to -16.5 volts, again a change of 6.5 volts, the plate current changes by only 1 ma. That is, for a linear change in control grid voltage, we do not get a linear (proportional) change in plate current. Therefore, the equivalent resistance of the electron stream changes in a manner that is not proportional to grid voltage changes; the resistance changes in a nonlinear manner.

The term nonlinear impedance has come to have a rather broad meaning among engineers and designers. Even the diode is known as a nonlinear impedance when used as a mixer. Later in this lesson, its application as a mixer is discussed. It is nonlinear in the sense that it has the same effect upon the combined r-f and oscillator signal as the previously discussed mixer has; negative swings of the oscillator signal do not produce an output equal to that produced by the positive swings. The output signal has a nonsymmetrical envelope and therefore contains a recoverable resultant. A nonlinear impedance may thus produce a useful distortion of the applied signal.

When a-c voltages, such as r-f voltages, are applied to the control grid, so that the plate current variations are high-frequency a-c variations, we speak of the tube's electron stream as an impedance rather than as a resistance. If the effect of a tube's action is such that negative swings of the input signal do not produce an output equal to the positive swings, the tube is called a nonlinear impedance. Consequently, engineers often call converter tubes nonlinear impedances or nonlinear circuits.

A Simple Converter Stage. A practical converter circuit — widely used in early

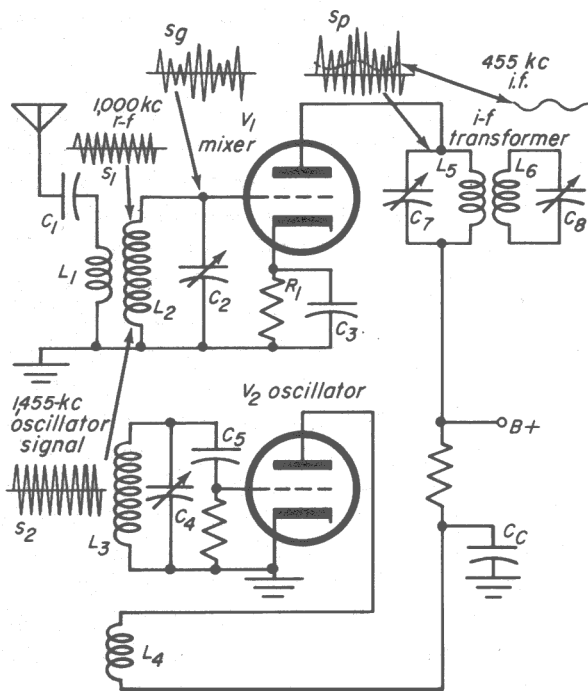


Fig. 31-8

broadcast-band superheterodyne receivers, and still widely used in UHF receivers — that operates with a nonlinear characteristic as just described, is shown in Fig. 31-8. It uses a separate triode oscillator and a triode plate detector as mixer. Let us follow a signal through it from the antenna to the secondary of the input i-f transformer. Let us pick a moment when the incoming r-f signal is unmodulated — when the microphone at the broadcast studio is not impressed by a sound wave. The r-f signal, S_1 , will have an unvarying amplitude, as shown. So will the steady oscillator signal, S_2 . The r-f flowing in the primary winding, L_1 will induce an r-f current in secondary L_2 . The oscillator signal in L_3 will induce a current at oscillator frequency in L_2 , since L_3 and L_2 are mutually coupled. S_1 and S_2 will combine in L_2 . The signal applied to the grid of the mixer tube, V_1 , will therefore have the waveform S_g with upper and lower outlines equal in amplitude and opposite in phase. Mixer tube V_1 is biased close to cutoff by the voltage drop across cathode resistor R_1 . (C_3 prevents any signal from developing across R_1 .) Because of the near cut-off bias, V_1 is operating on the nonlinear part of its e_c-i_b curve. Therefore, the signal in its plate circuit will be distorted to the shape illustrated by waveform S_p . The output signal S_p

is the combination of the oscillator and incoming r-f signals, after having been heterodyned, amplified in proportion to the gain of the tube, and distorted by the nonlinear transfer curve. Its envelope, with unequal upper and lower halves, and a frequency of 455 kc, produces in L_5 a resultant current, indicated by the dashed line through S_p . L_5 is tuned to 455 kc, and therefore responds to the resultant current. The resultant current in L_5 induces in L_6 a 455-kc current that contains no appreciable trace of either r-f or oscillator signal.

It is interesting to note that the oscillator may operate at a frequency higher or lower than that of the incoming r.f. by an amount equal to the i.f. In the case of the AM broadcast receiver, the oscillator is always above the incoming r-f signal. It could operate at a frequency that would always be 455 kc lower than the r.f. It would still produce a difference frequency of 455 kc. But then the tuning range of the oscillator tank circuit would be impracticably large. When the oscillator is higher than the r.f., it can track with the broadcast band signals if its range is 985 kc to 2,105 kc. But when the oscillator frequency is lower than the r.f., its range must be 75 kc to 1,195 kc. The frequency ratio of the oscillator range in the first case is only a little more than 2:1 (2,105/985). But in the second case it is almost 16:1 (1,195/75). A variable capacitor suitable for the 16:1 ratio would have to have a capacitance range equal to the square of the frequency ratio. It would not be desirable nor mechanically feasible.

At very high frequencies, however, the oscillator is sometimes designed to have a frequency lower than the r.f. This is done because an oscillator is more stable if it is operated at the lower of two suitable high frequencies. Frequency range is not a problem at very high frequencies. Whether the oscillator is operated above or below the frequency of the incoming signal, its frequency range is nearly the same, because there is little percentage difference between upper and lower operating frequencies in VHF work.

When the incoming r-f signal is carrying audio information — that is, when the carrier

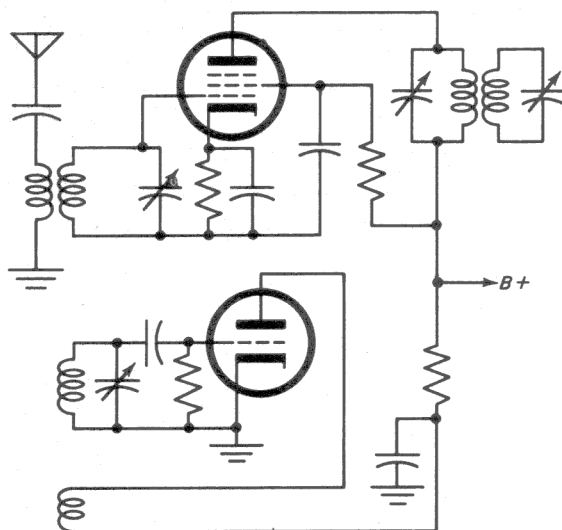


Fig. 31-9

is accompanied by sidebands — the sidebands will produce sideband i-f frequencies. Thus the 455-kc signal will carry audio modulation to the diode detector.

Greater gain can be achieved in the converter stage just described by substituting a pentode plate detector for the triode plate detector, as the mixer tube. In this case, however, the signal-to-noise ratio will be less favorable, because the additional electrodes in the pentode increase the tube noise. On very weak signals, the tube noise would be quite noticeable. A schematic diagram of the circuit is shown in Fig. 31-9.

31-3. THE PENTAGRID CONVERTER

The pentagrid converter combines the functions of oscillator and mixer in one tube. The cathode and the first two grids, as shown in Fig. 31-10a, constitute an oscillator triode. The last three grids and the plate constitute the mixer portion.

The first grid, G_1 , is the oscillator control grid. It is the grid nearest to the cathode. G_2 is called the oscillator-anode grid because, when B+ is applied to it, it functions as a plate, or anode, for the oscillator section. It attracts electrons because of the positive voltage, but does not attract all the electrons. A greater proportion of the electrons go past G_2 to the actual plate in the mixer section of the tube.

Let's follow the electrons from the cathode. As they leave the cathode and ap-

proach G_2 , which has a positive charge, they are accelerated. They pass G_2 , but do so in spurts at the frequency of the oscillator; then they are slowed up as G_2 tries to pull them back. But, having passed G_2 , the electrons already feel the pull of G_3 , which also has a positive potential. Some of the electrons are captured by G_3 , but most pass through its spaces, moving toward G_4 . However, G_4 is biased negatively with respect to the cathode; the operation is approximately Class AB. This negative bias repels the oncoming electrons, so they do not readily pass through G_4 and on to the next positive anode, G_5 , and to the plate. They bunch up into a cloud, or space charge, between G_3 and G_4 , as shown in Fig. 31-10b. This space charge is pulsating at the oscillator frequency, because the electrons that maintain it arrive in pulses, corresponding to the oscillator signal swings of G_1 . As G_1 swings positive, many electrons rush from the cathode. Thus, the space charge near G_4 is pulsating (changing in number of electrons) at the oscillator frequency. To the mixer plate, the pulsating cloud of electrons can be considered to be like a cathode — that is, like a plentiful source of electrons. For this reason, the cloud is called a *virtual cathode*. The positive potential on the mixer plate attracts the cloud. If an r-f signal applied to G_4 swings it momentarily positive, a large number of electrons rushes from the cloud through the spaces between the turns of G_4 , through G_5 , and to the mixer plate. If the cloud happens at that instant to be large (due to a fresh pulse arriving), a particularly large number will rush through to the mixer plate. If it happens to be small, as it is in between pulses, not so large a number will rush through the plate. In other words, the number of electrons arriving at the mixer

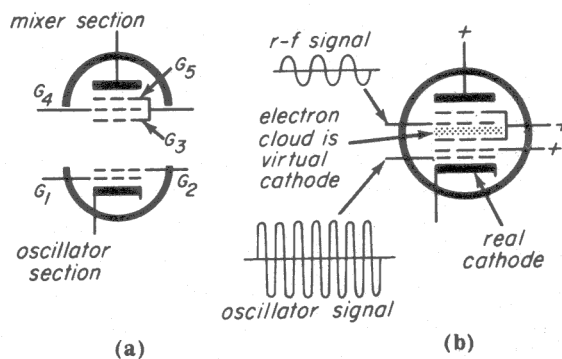


Fig. 31-10

plate is varied by both the oscillator signal and the r-f signal. Sometimes, the effects on plate current due to the r-f signal and to the oscillator signal add; sometimes they oppose each other, depending on whether the signals are in phase or out of phase. Consequently, in the mixer tube's plate circuit, the envelope of the stronger signal will be heterodyned by the smaller signal, at a frequency equal to their difference as indicated in Fig. 31-7. Incidentally, G_5 gives the tube the property of tetrode and consequently higher gain than if G_5 were not present.

A conventional circuit for a pentagrid converter, 6A7 or 6A8, is shown in Fig. 31-11. The tuned circuit L_2C_3 selects the desired incoming r-f signal. This signal is applied to the mixer grid, G_4 . The oscillator section uses a tickler-feedback oscillator circuit. L_3C_4 form the oscillator tuned circuit. L_4 is the feedback coil. G_1 serves as the control grid and G_2 the plate for the oscillator. Grid leak bias is developed across R_2 . The voltage drop across R_1 provides minimum bias for the mixer tube, even if the AVC voltage is zero. The cathode bypass capacitor C_1 bypasses the r-f or oscillator voltage that would ordinarily appear across R_1 , and thus serves to prevent degeneration. Decoupling filters R_3C_5 and R_4C_7 keep oscillator-signal and r-f signal surges from getting into the B+ supply and thereby reaching other stages.

R_5C_6 serves as an AVC filter. C_6 serves an additional function by completing the L_2C_3 tank circuit connection. Using C_6 in this fashion allows the variable capacitor frame to be mounted on the grounded chassis without shorting out the AVC voltage, by way of the grounded rotor.

In a pentagrid converter (Fig. 31-11) the effect of the oscillator signal upon the electron stream of the mixer is much greater than is the effect in the circuit previously discussed. Circuit constants are chosen so that the tube will be driven to cutoff or slightly beyond cutoff during each negative swing of the oscillator signal. Then as the signal swings to its positive peak, plate current increases and approaches saturation. Plate current actually decreases slightly

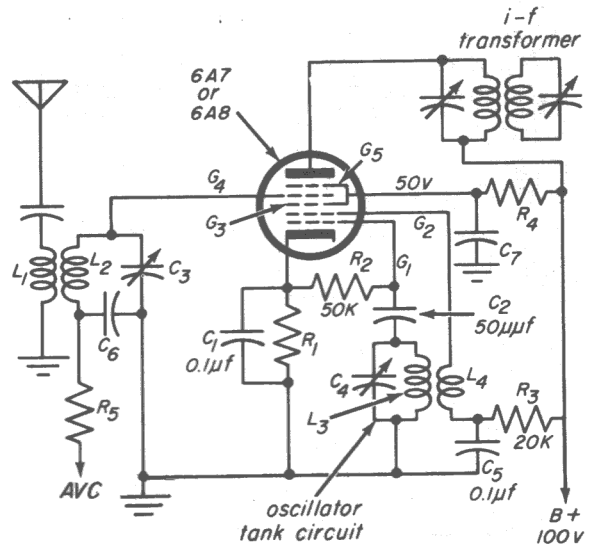


Fig. 31-11

at the peak positive swing of the oscillator signal on the grid, because the momentarily positive grid itself captures some of the electrons, which are then not available as plate current electrons. Because the oscillator has such a great effect upon the plate current, it actually varies the *transconductance* or gain capability of the tube.

When the instantaneous voltage on the oscillator grid is negative, plate current is small, and the slope of the transconductance curve approaches the horizontal. At cutoff it is horizontal. When the instantaneous voltage on the oscillator grid is positive, plate current is large and the slope of the transconductance curve is steep, approaching the vertical rise, until oscillator grid current occurs at X, and the curve turns downward.

Because the slope of the curve is steepest during the positive swing of oscillator grid voltage, transconductance is high on the positive swing, and the corresponding half cycle in the output is large, as the shaded area in the figure shows. On the negative swings, when transconductance is low, the corresponding half cycle is small.

In short, the *gain of the tube as a whole* follows the swings of the oscillator signal. This means that the gain for the r-f signal also follows the swings of the oscillator grid signal. Therefore, r-f gain is high when oscillator grid voltage is positive, and r-f

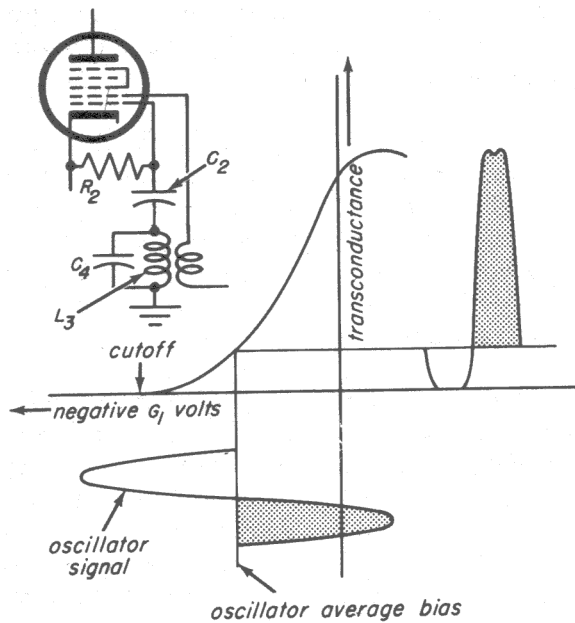


Fig. 31-12

gain is low when oscillator grid voltage is negative (31-12).

The desired signal is produced in the manner illustrated by Fig. 31-2, with an important exception. The r-f signal in the plate circuit varies in amplitude as the transconductance varies (Fig. 31-13a). This means that on the positive swings of the oscillator-grid voltage, the r.f. in the output is stronger and modulates the oscillator's plate current half cycles shown at *b*, more strongly than it does when the oscillator grid voltage is negative. As a result, the outline of the plate current of the mixer has the upper half of its envelope deeply modulated and the lower half imperceptibly modulated, or not modulated at all (due to approaching cutoff and reduced gain) as shown in Fig. 31-13c. The dotted line shows the recoverable resultant, the i-f signal to which the plate load is tuned.

Interaction Between Signal Grids. Even though G_3 was included in the design of the pentagrid converter to act as a shield that would minimize capacitive coupling between G_1 and G_4 , slight interaction between the two grids does occur, due to space-charge coupling. Oscillator energy flows in the r-f input circuit, because the pulsating space charge near the r-f grid induces a current at oscillator frequency in the r-f grid circuit.

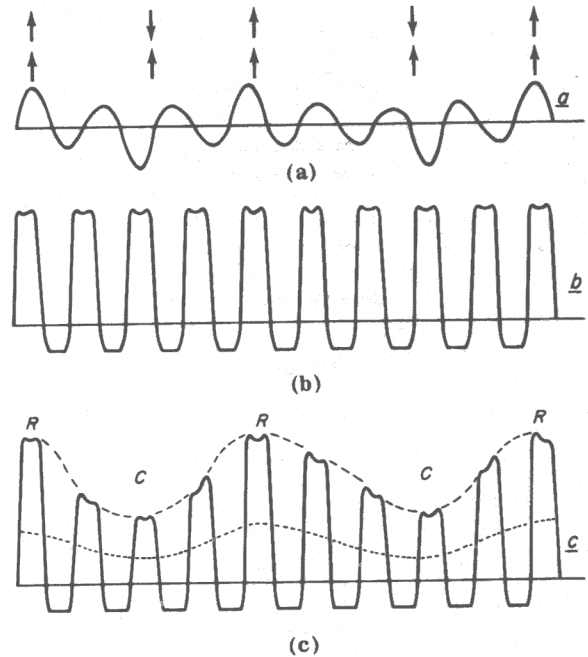


Fig. 31-13

At the high frequencies of the short-wave band, the effect is quite marked. Oscillator currents are easily induced in the r-f circuit because the percentage difference between r-f and oscillator frequencies is much smaller for the short-wave band. In terms of percentage, the oscillator frequency is close to the resonant frequency of the r-f input circuit, and is able to induce a considerable voltage across it. When oscillator energy finds its way into the r-f circuit, the oscillator operation is somewhat affected by the energy loss, causing a shift in oscillator frequency. When a very strong r-f signal is coming in, each positive half cycle makes the r-f grid attract electrons from the space charge. The oscillator frequency may be altered enough thereby to cause it to lock in with, or synchronize with, the r-f signal. When this happens, there is no difference between the oscillator frequency and r.f. The intermediate frequency disappears. There is no output from the set.

The tendency to interaction at short-wave frequencies was an inherent fault of early pentagrid converters

The Pentagrid Mixer Tube, 6L7. This is a five-grid mixer tube only. It requires a separate oscillator tube. But it retains the principle of injecting both oscillator and r-f signal into one electron stream by means of

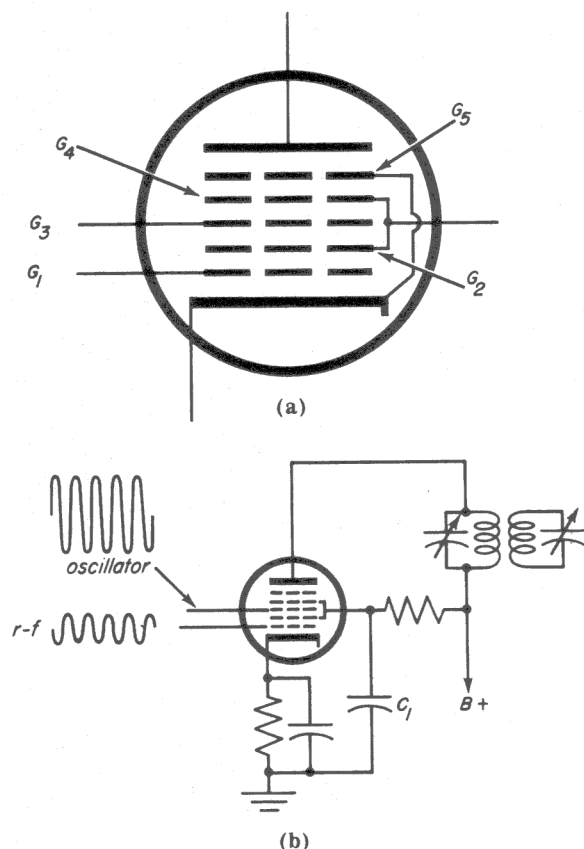


Fig. 31-14

independent grids. However, it reverses the order of injection. In the 6A8, the oscillator signal was developed on the first grid (G_1), and the r-f signal was applied to the fourth grid (G_4). In the 6L7, the r-f signal is applied to the first grid (G_1) and the separately generated oscillator signal is applied to the third grid (G_3).

The five grids are arranged as shown in Fig. 31-14. G_1 is the r-f signal mixer grid, G_3 the oscillator-signal injector grid, and G_2 , held at r-f ground potential by bypass capacitor C_1 , and at +150 volts, serves as an electrostatic shield. This reduces the capacitance between G_1 and G_3 to a minimum. In addition, G_2 serves as a screen grid. G_4 , connected internally to G_2 , also serves as a screen grid. G_5 is a suppressor grid. Because of the inclusion of G_2 , G_4 and G_5 , the tube has characteristics similar to a pentode. There is an advantage in injecting the oscillator at G_3 . The moving electrons, going from cathode to plate, have already passed the mixer, or r-f signal grid before reaching the oscillator grid. They have passed through an isolating shield as well. Thus, any effect

that the oscillator voltage has on the electron stream is not felt by the r-f signal (mixer) grid.

The effect of the r-f signal upon the electron stream cannot appreciably disturb the oscillator operation because oscillation depends upon a separate stream of electrons in another tube, and because the oscillator voltage is quite large compared to the r-f signal voltage.

The 6L7 performs very satisfactorily with negligible interaction or locking-in tendency. When first produced, it was very popular in short-wave receivers. But a steady demand for oscillator and mixer functions in one bulb led to the development of tubes that rivalled it in performance without requiring a separate oscillator tube.

31-4. IMPROVED CONVERTER TUBES

Ingenious structural arrangements, based on analysis of the faults of earlier converters provided several solutions to the problems of interaction.

Triode-Heptode. The triode-heptode (3-element/7-element) type, 6J8-G, is constructed as shown on the side section view of Fig. 31-15a. The tube is shown schematically at b. The oscillator triode uses an independent stream of electrons from its own section of the cathode. It has its own separate anode, or plate. The grid is shared in common with the mixer section by means of an extra winding called the injector grid, located, as shown in the figure, between the two screen grids. Injector and oscillator grids are connected together.

Any signal voltage developed on the oscillator grid is also applied to the injector grid, so that the latter varies the electron stream of the mixer. This is outer grid injection, as in the 6L7, characterized by minimum interaction between oscillator and r-f grid signals.

As long as the supply voltages and bias are held steady, the tube is very stable. When the tube is used for short-wave reception, AVC is not recommended for its r-f

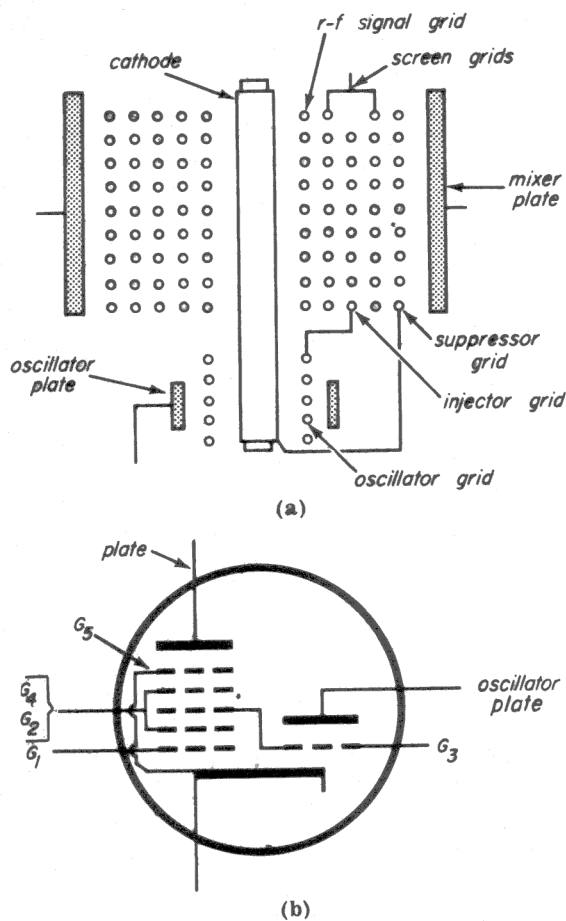
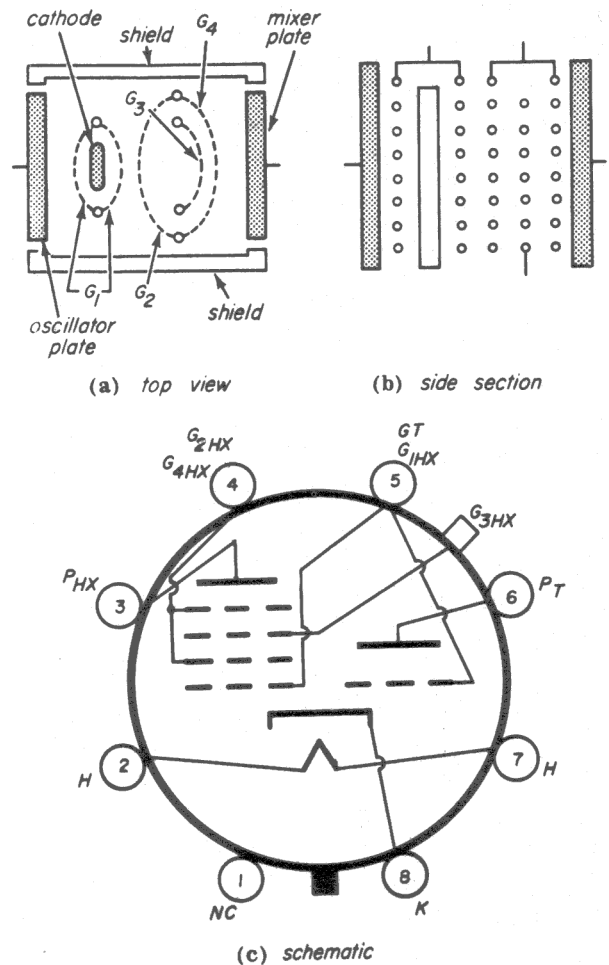


Fig. 31-15

grid. Because the r-f or control grid is the inner grid, any change of its bias has marked effect upon the electron stream. Even though the coupling between G_1 and G_3 is greatly minimized by the tube's construction, the effect upon the electron stream enables the control grid bias to slightly influence the oscillator's operation and may cause some detuning at short-wave frequencies to occur.

The tube is free of locking-in action, and AVC applied to an r-f stage preceding the converter provides adequate regulation of gain at the input to the converter.

Triode-Hexode. The construction of the triode-hexode (3-element/6-element) converter, 6K8-G, successfully minimizes interaction and at the same time allows AVC to be applied to the control grid, even at short-wave frequencies. In this design, G_3 of the hexode section is the mixer grid. When AVC is applied to it, the change of bias does not effect the oscillator stream of electrons. The electrons going from cathode to the



(c) schematic

construction of triode-hexode, 6K8-G

Fig. 31-16

mixer plate have already passed G_1 , the oscillator-signal injection grid, before reaching the r-f mixer grid; also note that the oscillator electron stream is independent of the mixer stream.

Figure 31-16a shows that the electron stream for the mixer and the electron stream for the oscillator move in opposite directions. Though they originate in a common cathode, they cannot interact through it because they leave by opposite faces and because the cathode is held at ground potential for signal frequencies. Electrostatic shield plates, held at cathode potential, almost completely eliminate capacitance between oscillator and mixer electrodes.

The half of G_1 on the mixer side of the cathode provides inner grid injection of the signal developed by the oscillator on the other half of G_1 . G_2 serves as a screen grid

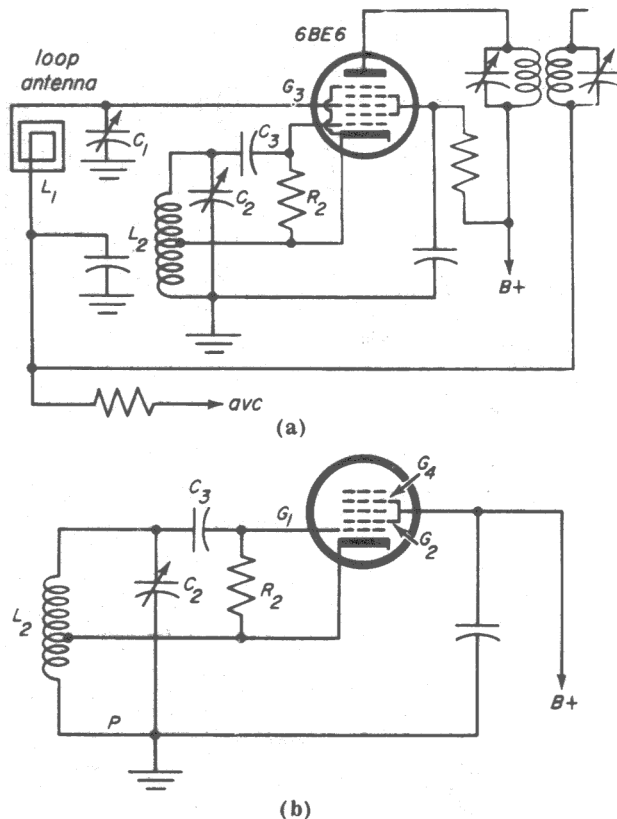


Fig. 31-17

and as an electrostatic shield eliminating capacitance between G_1 and G_3 . G_4 is another screen grid. No suppressor grid is used, so G_2 and G_4 must be operated at voltages low enough to avoid secondary emission from the plate. Side views of structure and schematic representation of the tube are given at *b* and *c* respectively.

The 6K8-G has its base connections so arranged that it is a suitable direct replacement for the formerly popular pentagrid converter, 6A8. No wiring changes are necessary. It is simply plugged into the socket that has accommodated the 6A8.

6SA7 and 6BE6 Type Converters. The 6SA7 and the 6BE6 type converters are essentially converters that use a Hartley-type oscillator circuit; the mixer has pentode-tube qualities.

A schematic diagram of the circuit is shown in Fig. 31-17a. The oscillator portion is shown in Fig. 31-17b. The oscillator circuit is comprised of the tank circuit L_2C_2 , the grid-leak bias network is made up of R_2C_3 ; G_1 serves as the oscillator grid; G_2

and G_4 serve as the oscillator anode. The cathode is connected to the tap on L_2 that determines the amount of oscillator feedback. The oscillator circuit is the series-fed Hartley, sometimes called the electron-coupled Hartley oscillator.

In the complete schematic diagram (Fig. 31-17a), note that the loop antenna L_1 and C_1 form the r-f input. The incoming r-f signal is applied to the mixer grid, G_3 . G_3 is enclosed in the shield provided by the bypassed screen grids, G_2 and G_4 . This shield eliminates capacitive effects between G_1 and G_3 . G_2 differs from the usual screen grids. In addition to the wire helix, or winding, two specially shaped plates, attached to the struts that hold the winding, serve as collectors of electrons that stray, or are deflected from their normal course by signal voltages. Interaction between r-f and oscillator grids, due to these stray electrons and to capacitance between the grids, is thus effectively minimized by G_2 . A top-view of the electrode arrangement of the 6BE6 type is given in Fig. 31-18.

When the tube is used for operation at the frequencies of the short-wave bands, care must be taken to keep the *external* capacitance between r-f and oscillator grids at a minimum if interaction is to be avoided. It does no good to eliminate interelectrode capacitance within the tube if equivalent capacitance due to layout of parts and wiring is substituted. In repair of circuits using this tube at high frequencies, the service technician should keep this in mind. About $1\mu\mu\text{f}$ is the maximum permissible external

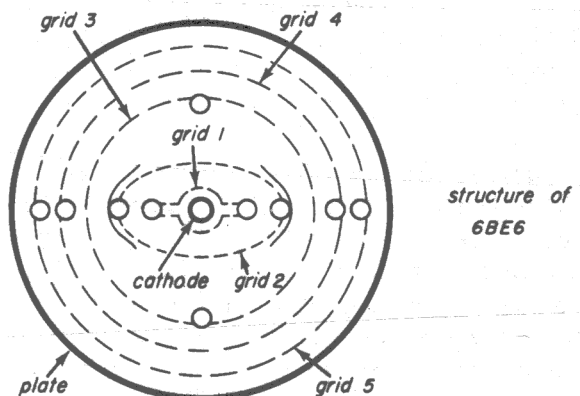


Fig. 31-18

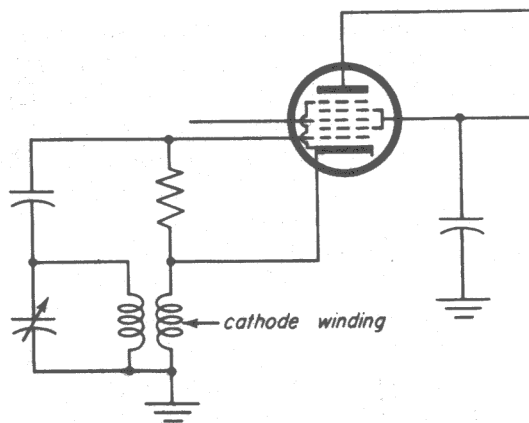
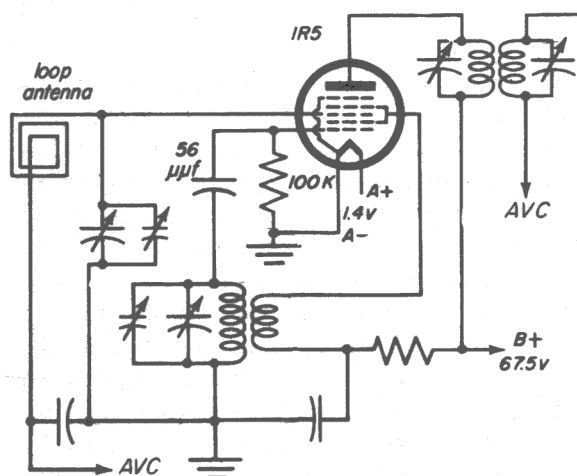


Fig. 31-19

capacitance in short-wave applications of this type of pentagrid converter.

Although Fig. 31-17 shows a single tapped inductor serving as both tank coil and feedback coil, the two-winding (tank and cathode) coil arrangement may also be used with the 6BE6, as shown in Fig. 31-19. The cathode winding is the one with fewer turns. Care must be taken to get the polarity of the cathode winding appropriate for the polarity of the tank coil. If the leads to the cathode winding are reversed from their correct position, positive feedback will not occur, and no oscillation will result. This circuit is a Hartley or electron-coupled Hartley oscillator. Other versions of the 6BE6, are 6SA7, 12BE6, 12SA7, 6SB7-Y, 6BA7.

Battery-Operated Converter Tubes. Battery-operated converter tubes are pentagrid converters in glass bulbs of four different types; 1A7GT (octal), 1LA6 (lock-in), 1R5



converter stage using 1R5

Fig. 31-20

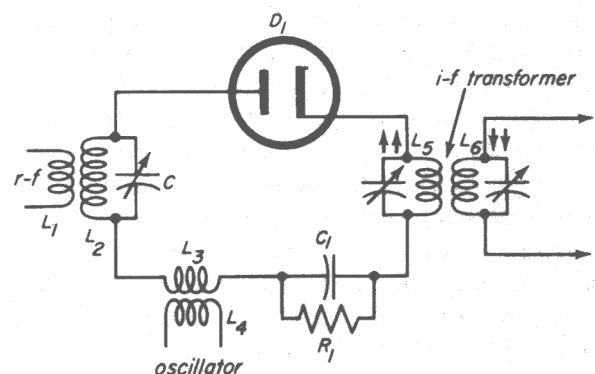
and 1L6 (miniature), and 1E8 (subminiature). A circuit for the most widely used of these, the 1R5, is shown in Fig. 31-20.

These tubes have no indirectly heated cathode. In place of the cathode is a d-c heated filament, coated with a material capable of emitting a plentiful supply of electrons at a relatively low temperature. The glow from the filaments is so faint that it is often difficult to tell if the tubes are lit. In effect, the filament is the cathode or source of electrons. It is designed to emit at a low temperature in order that battery current, required to heat it, may be conserved as much as possible. Only 1.4 volts at 50 ma is required for the filaments of the first four of these tubes. The last, 1E8, requires only 1.25 volts at 40 ma.

Although the 1R5 is patterned after the 6BE6, it has some important differences. It does not have the collecting plates for stray electrons, nor does normal operation of it require G_2 and G_4 to be held at ground potential for r. f. On the other hand, it has neither the high conversion gain nor the stability of the 6BE6.

31-5. DIODE TUBES AND CRYSTAL RECTIFIERS AS MIXERS

The i-f component of two signals that heterodyne each other in an appropriate input circuit can be recovered by the rectifying action of a diode tube. A circuit demonstrating how this may be done is presented in Fig. 31-21. The r-f signal in L_1 induces a signal in L_2 , tuned to the incoming carrier. Oscillator current flowing in L_4 induces a



diode mixer for VHF and UHF

Fig. 31-21

signal into L_3 . The signals in L_2 and L_3 , are in series with each other, and add or cancel according to their phase relationships. The oscillator signal is usually the stronger of the two, and is modulated by or heterodyned with the r-f signal. Diode V_1 rectifies this complex signal, eliminating one half envelope. The remaining half envelope appears in the diode tube load, which consists of L_5 and R_1C_1 . L_5 is tuned to the resultant, or intermediate frequency, thus separating it from the other signal frequencies in the load. L_6 , also tuned to the resultant, passes it on to the next stage in the receiver, R_1C_1 serves to bias the diode plate, by the equivalent of grid-leak bias. Thus the charge on the plate is negative, and is only slightly less than the peaks of the positive half cycles. The diode conducts only during the peaks, and thus loads the input circuit less. Its output follows the peak level closely. Since the varying peak level is the desired i-f signal, this action provides the maximum possible recovery of the desired signal.

An important advantage of the diode tube mixer is that it adds less tube noise to the signal than multigrid converters. Tube noise is roughly proportional to the number of electrodes bearing supply voltages interposed in the electron stream. The diode has only two signal-handling electrodes. Therefore, it produces less noise than other electron tube converters.

Unlike the other mixers so far discussed, the diode tube introduces a conversion loss, as opposed to a conversion gain. This must be expected, since the diode cannot amplify. This does not make it a poor choice for its purpose, because, at the extremely high frequencies (over 300 mc) for which the diode mixer is used, the pentagrid converters would also introduce a loss, an even greater loss than the diode. The pentagrid converter could not operate as an amplifier at a frequency such as 350 mc, because in the time it would take an electron to leave the cathode and cross the relatively wide space to the plate, an r-f cycle would be over. The electron stream could not be made to vary appreciably at the high r-f rate. In addition, the interelectrode capacitances of the tube would effectively bypass the

signal. But special diode tubes, with small size electrodes, closely spaced, can still rectify such signals, because the *electron transit time* — the time required for the electron to cross the cathode-to-plate distance — is less than the time required for an r-f cycle, and because the interelectrode capacitances are small.

At still higher frequencies — above 500 mc, for example — the electron transit time of even the diode is too long; the capacitances are too great. Miniature crystal rectifiers are used for mixing at such frequencies. In these, the electrons travel an exceedingly short distance to get from one electrode to another — from crystal to cathode whisker — because the electrodes are in contact. Although the electrodes are so close together, capacitance effects between them are relatively small. This is so because the area of contact is so small that, if it were a black dot on a white paper, it would be invisible unless you used a magnifying glass.

The crystal is used in a circuit similar to the diode tube circuit, except that the R_1C_1 combination is omitted. Crystals work better without bias, because their input volts-output current characteristic curve bends most sharply at the zero bias point. Crystals have greater conversion loss than diode tubes and have a poorer signal to noise ratio.

31-6. CONVERSION TRANSCONDUCTANCE

In comparing the efficiency of various converter tubes, some method of rating them is required. Since their job is to produce an i-f signal in the plate circuit when an r-f signal is applied to the control grid, we need a term that expresses the ratio of the change in plate current at the intermediate frequency to the change in control-grid voltage at the radio frequency. This ratio is the *conversion transconductance*. It differs from simple transconductance by taking into account the fact that the desired signal in the plate circuit is not the same signal applied to the control grid, but is a new signal of different frequency.

It may be expressed in a formula as follows:

$$G_c \text{ (in } \mu\text{mhos)} = \frac{\text{change in plate current} \text{ (}\mu\text{a) at i.f.}}{\text{change in grid volts at r.f.}}$$

(The formula is accurate only for small values of grid volts.)

Let us apply the formula to an example. Suppose a 0.5 volt signal at 1,000 kc is applied to the control grid of a 6SA7, rated as having a G_c of 450 μmhos . What current at the i.f. will flow in the plate load?

Substituting numerical values, we get

$$450 = \frac{I_p}{0.5}$$

$$I_p = 0.5 \times 450 = 225 \mu\text{a} = 0.000225 \text{ ampere}$$

Stated in words, the formula shows that when an r-f signal of 0.5-volt amplitude is applied to the control grid of the 6SA7, an i-f signal current of 0.000225 ampere flows in the plate load.

(If the same tube were operated not as a converter, but as a straightforward amplifier, with the same frequency of signal taken off at the output as is applied to the input, the change in plate current would be three or four times greater; that is, the transconductance would be three or four times higher than the conversion transconductance.)

Table A presents the rated conversion transconductances of the tubes discussed in this lesson:

The actual gain of a converter stage is not wholly dependent upon the conversion transconductance. Other factors also influence it. For example, a well-designed stage using a 6J8 may be made to provide about as much gain as a stage using the 6A8, even though the 6A8 tube has a much higher conversion transconductance. This is possible because the design of the 6J8 more effectively isolates the output circuit from the input circuit. Therefore, an i-f transformer with a high-impedance primary may

TABLE A - TRANSCONDUCTANCES

Tube	Conversion Transconductance (micromhos)
6A7	550
6A8	550
6J8	290
6K8	350
6SA7	450
6BE6	475
6BA7	950
6SB7-Y	950
1R5	300
1E8	150

be used as the plate load. Large voltage variations across the high impedance are not able to feed back out of phase to the input and cause decreased gain. In the 6A8, however, input and output circuits are not so well isolated. A transformer with a relatively low-impedance primary must be used as the plate load. Since a small current change in a high impedance can develop as large a signal voltage as a greater current change in a low impedance, the 6J8 can provide about the same gain as the 6A8.

Harmonic Mixing. At extremely high frequencies, because of the limit imposed by electron transit time, many tubes cannot be made to oscillate. Thus, a tube which might oscillate vigorously at 100 mc might not oscillate at all at 300 mc. In a converter circuit which required an oscillator signal at 300 mc, such a tube could still be used. It could be tuned to oscillate at 100 mc and its grid bias adjusted so that the output would be rich in harmonics. Its third harmonic would have a frequency of 300 mc. This could be coupled into a diode or crystal mixer in a circuit like that of Fig. 31-20. The third harmonic and the incoming signal would heterodyne each other in the mixer and produce the intermediate frequency.

31-7. CONVERTER TROUBLES

Although the common troubles that occur as a matter of course in tuned-amplifier

stages can also be expected to occur in the converter stage, there are several that are particular to this stage.

Oscillator Failure. The most common cause of trouble in the converter stage is failure of the oscillator. When there is no oscillation, no i.f. is produced and no audio output is heard. The simplest test for oscillation is measurement of the oscillator's grid bias. When there is no oscillation, there is no bias. During normal operation, bias is between -10 and -15 volts for most converter tubes used to cover the broadcast band. It is somewhat less, -4 to -8 volts, for the short-wave band, and still less, -2 to -5 volts for VHF.

Only a sensitive instrument such as a vacuum-tube voltmeter or a 20,000 ohms-per-volt multimeter should be used to take the reading. A less sensitive instrument may draw enough current to kill the oscillation of even a normal tube, by making the loss in the grid circuit greater than the amount of energy fed back from the anode circuit (or cathode circuit if a Hartley oscillator is used).

A dead oscillator may also be revealed by using a signal generator to supply the signal that the oscillator fails to supply. The receiver is tuned to the dial setting of a strong station known to be on the air. The generator is set to a frequency higher than the station's carrier frequency by an amount equal to the i.f. The unmodulated output of the generator is then injected into the appropriate mixer grid. If the station is heard now, the oscillator must be dead, or operating far off its normal frequency. If it is off frequency, it will still generate a measurable bias which may be read with the multimeter. Off-frequency operation may be due to accidental mistuning of the oscillator circuit or shorting of turns in the oscillator tank coil, with consequent change of inductance and resonant frequency. It is a rare occurrence.

Drift. You will occasionally encounter receivers that do not stay on station. Though the receiver may be properly tuned in when first switched on, after a five or ten minute warmup, the station no longer comes in. The

receiver has to be retuned to bring the station back in. The station indicator points to a slightly different frequency on the dial, but the incoming carrier has not changed frequency. However, the oscillating tank circuit has. Heat has changed the physical dimensions of some frequency-determining component, such as a capacitor or an oscillator tank inductor. A change of either capacitance or inductance, resulting from change in size, will also change the resonant frequency. In order to compensate for the changed component value, the oscillator section of the variable tuning capacitor has to be re-tuned to a slightly different position. That is, it must be set at a wrong position. Consequently, the dial pointer moves to a wrong indication

In the broadcast receivers, this drift is more noticeable at the high end of the dial, where a small change of either capacitance or inductance in the resonant circuit of the oscillator will make a large change in the resonant frequency of the oscillator. Drift is usually due to a heat-sensitive oscillator coil, padder capacitor, or faulty converter tube.

In receivers meant for the reception of high-frequency signals, such as FM receivers, drift is a difficult problem. Manufacturers try to counteract it by the use of compensating components, or by automatic-frequency-control circuits.

Flutter. Flutter, named for the sound it produces from the loudspeaker, is due to rapid variations of oscillator frequency; these variations result in a station's being tuned in, tuned out, tuned in, tuned out, etc., at a rate lower than the lowest audio frequency, but high enough to convey the impression of fluttering.

It may be caused in the following two ways:

1. By a converter tube whose oscillator frequency is sensitive to changes in B+ level. As a station is tuned in, the audio signal may cause the power output tube to draw more power from the B+ supply, thereby lowering the B+ level slightly. Lowered

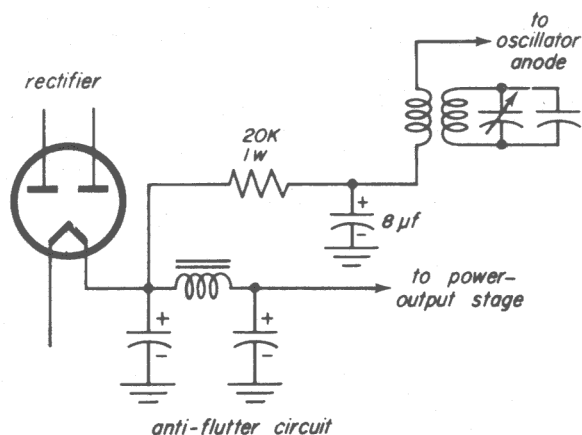
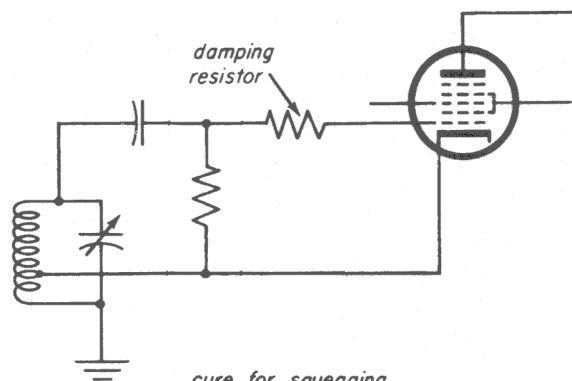


Fig. 31-22

B+ alters oscillator frequency. The station is tuned out. As the audio signal ceases, the power output stage draws less current, B+ rises, and the oscillator frequency returns to normal. The station comes in, and the cycle repeats. This fault usually can be cured by taking the B+ supply to the oscillator anode from a different part of the B+ bus instead of the supply point for the power-output tube. A decoupling filter, consisting of a 20,000-ohm resistor and an 8-μf capacitor, should isolate the anode supply point from the B+ take-off point. The cathode or filament of the rectifier tube is a good take-off point (see Fig. 31-22).

2. By a converter tube whose oscillator frequency is sensitive to abrupt AVC changes. As a station is tuned in, AVC develops a change in grid bias on the converter r-f grid. Interaction with oscillator grid, or with space charge changes the oscillator frequency. The station is tuned out, AVC bias decreases, and interaction decreases. The oscillator frequency returns to normal. The station comes in again and the cycle repeats. This fault is most easily cured by removing AVC from the r-f grid, and substituting fixed bias.



cure for squegging

Fig. 31-23

Flutter is encountered only on the short wave band, where a very small percentage change in oscillator frequency is sufficient to tune out a station, because it makes a large percentage change in the i.f.

Squegging. This effect produces a harsh howl or whistle from the loudspeaker. It is caused by the oscillator's stopping and starting, stopping and starting, at a high repetition rate. It occurs at the high end of the short-wave band when the oscillator section of the variable capacitor is opened to minimum capacitance. The reactance of the oscillator tank circuit is highest for this setting. The vigor of the oscillation may be great enough to develop excessive grid bias, which cuts off the tube. Oscillation and audio-output stop. The oscillator bias drains off through oscillator grid-leak resistor. Oscillation resumes and the audio output re-appears. The bias builds up to cut-off, and the cycle repeats. The effect can occur on either broadcast or short-wave bands. Usually, it can be eliminated by connecting a small carbon resistor of a few hundred ohms in series with the oscillator grid, right at the socket lug (see Fig. 31-23). This resistor has a damping effect that limits the strength of oscillation more at the high end of the band than at the low.